Innovation Diffusion: Application of Agent-Based Modelling and Simulation in a Case Company in Sultanate of Oman

Emad Summad, Mahmood Al-Kindi and Ahm Shamsuzzoha
Department of Mechanical and Industrial Engineering
Sultan Qaboos University
Muscat, Sultanate of Oman
esummad@squ.edu.om, kindim@squ.edu.om, ahsh@squ.edu.om

Abstract

Agent-Based Modelling and Simulation (ABMS) has increasingly been applied in diffusion of innovation research. The ABMS method is successfully implemented to different domains in business networks to study the diffusion of their innovation activities. This research therefore applies such ABMS method to a case company at Muscat, Oman with the objective to study the diffusion of its innovation activities to the public. The case company is a famous real-estate company in Oman, where it successfully diffused its innovative project to the public by using ABMS method. The results from the ABMS method were analyzed by using a common used platform like MATLAB - MathWorks software. This is an ongoing research and this paper presents the initial results from the model. Since the acquirement of data took too long for this specific project, the incorporation of real world data and validation and adaption of the model are tasks for further research.

Keywords
Agent-Based Modelling and Simulation, Innovation Diffusion, case company, Sultanate of Oman

1. Introduction

Diffusion of innovation is a critical activity that can be used to measure the likelihood that an innovation will be adopted by members of a given society or culture. It is considered as a theory that seeks to explain how, why and at what rate an innovation or new idea and technology spread. It examines how ideas are spread among group of people. Rogers (2003) proposes four main elements to spread innovation: the innovation itself, communication channels, time and a social system. An innovation activity is diffused in multi-step, where an opinion leader known an as adopter exerts a large influence on the behavior of individuals.

The adoption of an innovation depends on the relative advantage, its compatibility with the pre-existing system, its complexity or difficulty to learn, testability, potential for reinvention and its observed effects (Greenhalgh et al., 2005). The adoption of an innovation also depends on the fuzziness of the boundary of the innovation. An individual known as agent encourages an opinion leader to adopt or reject an innovation (Infante, 1995). In general, an innovation or new idea is defused by human interaction through interpersonal networks. If an innovation adopter discusses it with two individuals of a given social system and these two individuals become adopters of the innovation it then diffuses in a binomial expansion (Rogers, 1971).

The rate of innovation diffusion can be defined as the relative speed at which participants adopt an innovation. In case of diffusion process, some people are more apt to adopt innovation than others are. Several studies found that people who adopt an innovation at early stage have different characteristics that people who adopt a later stage (Valente and Davis, 1999; Wejnert, 2002; Rogers, 2003; Barker, 2004). It is therefore, important to understand the characteristics of target audience that will support or adopt of the innovation. The diffusion of an innovation is measured by the time necessary to adopt a specific percentage of the members of a social system (Choi et al., 2010). As some point in time, the innovation reaches a critical point or critical mass, when the number of adopters assure that the innovation is selfsustaining. According to Rogers (2003), cumulative number of individuals that have adopted an innovation can be classified into five categories namely, innovators, early adopters, early majority, late majority and laggards.

Within the scope of this research, a special model for innovation diffusion known as Agent-Based Modelling and Simulation (ABMS) is applied to a case company at Muscat, Oman to analyze its innovation activities. The primary data is collected from the case company and initial results are highlighted in this research.

2. Literature Review: Available Models for Innovation Diffusion

Innovation diffusion models are generally categorized into two sub-divisions namely, conceptual models and mathematical models. In conceptual model, various aspects of innovation are considered such as determinants of diffusion, dissemination and implementations of innovation. This model represents the overall results of individual level processes of innovation diffusion. The conceptual model does not provide managers and researchers with quantitative tools to study the diffusion. On the other hand, mathematical modelling of innovation diffusion provides quantitative tools and has also attracted many researchers since early 1960s. This type of modelling is further divided into analytical (aggregate) and agent-based models (Kiesling et al., 2012).

The managers use aggregate model of innovation diffusion since 1960s in forecasting sales of new products and describing the spread of new products in market place (Mahanjan and Muller, 1979). This kind of seminal diffusion model describes the innovation diffusion by means of simple mathematical formulations, which is based on a mathematical description of flows between mutually exclusive and collectively exhaustive subgroups in a population. The concept of Bass model, which is a derivative of aggregate model, conceptualizes the diffusion of consumer by mass communication and spread by word-of-mouth and describes this process by means of a differential equation (Bass, 1969). According to Bass model, an individual’s probability of accepting a new product depends linearly on two factors: one, which is not associated to previous adopters, and one, which is related previous adopters.

Network heterogeneity diffusion model assumes that all individual in a population can have interpersonal communication with another individual contradicts even casual empirical evidence of diffusion within specific populations (Rogers, 2003). Another model of innovation diffusion known as disaggregate model is widely used in the social sciences. This type of diffusion model starts at the micro level has a rich potential in terms of a better understanding of the diffusion process and a tool for managerial action (Eliashberg et al., 1986). The disaggregate diffusion model is highly used to forecast the total market response and typically measured by the adopters numbers (Mahajan et al., 1990). This model is categorized in three broad areas namely, microeconomic models, stochastic models and agent-based-simulation model.

In case of micro-economic model, which is a derivative of disaggregate model typically characterizes the effect of risk attitude and learning under uncertainty on the adoption level. It assumes that the uncertainty associated with understanding of the innovation’s attributes, its price, pressure from other adopters to adopt it and their own budget (Mahajan et al., 1990). The stochastic model as a branch of disaggregate model of innovation diffusion deals with the consumer behavior in marketing, including brand choice and purchase incidence model. It provides the diffusion of innovations that consumers are not already familiar with because they lack of elementary diffusion mechanism (Manraj, 1995).

The agent-based model is the last category of disaggregate model defines the distribution of individual-level consumer characteristics and/or limited analysis of aggregate variables. This model deals with the elementary unit of modelling as a whole rather than individual or agent. It usually limited to the analysis of rational individuals’ decisions on the micro level and does not incorporate diffusion processes on the macro level.

3. Agent-Based Modelling and Simulation: Concept and Application

Bonaneau (2002) defines agent-based modelling as a mind-set consisting of describing a system from the perspective of its constituent units rather than a technology. These units which are the micro level are called ‘agents’ and may represent all kinds of actors (Bonaneau, 2002). According to Weiss (1999), agent can be described, as “….a computational entity such as a software program (...) that can be viewed as perceiving and acting upon its environment and that is autonomous in that its behavior at least partially depends on its own experience”.

The agent-based modelling and simulation, which is a part of mathematical modelling has been adopted increasingly in innovation diffusion research since it operates. This modelling approach includes heterogeneity effects and influence of different types of social network structures. It has been implemented as an aid to building theory, as tool to analyse real-world scenarios, support decision-making, and obtains policy recommendations (Kiesling et al., 2012). This kind of modelling is a bottom-up modelling approach that aims to capture emergent phenomena in complex systems by simulating the behavior and interactions of entities (Kiesling, 2011).

An important advantage of agent-based modelling and simulation is that it has the ability to capture the complex structures and dynamics of diffusion processes without knowing the perfect global interdependencies (Borshchev and Fillipov, 2004). This approach makes it possible to account for micro-level innovation drivers by modelling the adopters' behaviors and attitudes in a social network. The agent-based modelling and simulation differs from other available models is that it is not limited in its capacity to account for heterogeneity and social structure. This model has been applied in various fields such as, ecosystems management (Bousquet and Page, 2004), epidemiology (Auchincloss and Roux, 2008), pedestrian movements (Turner and Penn, 2002), criminology (Malleson, 2010), etc.

3.1 Agent Characteristics

The visitor of the case company is considered as the 'agent'. The various characteristics of the agent are listed in Figure 1. From Figure 1 it is seen that the characteristics of the agent are divided into two divisions namely, static and dynamic. Additionally, according to the position of an agent in the network, agent's nationality (such as Omani/Expatriate/Tourist) is also considered in the study. Furthermore, the agents are assigned to age groups according to the respective percentage shares in their nationality groups. Three age groups are considered: Children (0-19 years), Adults (20-70 years) and Seniors (70+ years). Particularly striking is the high percentage share of children of nearly 45 % within the Omani people, whereas, the percentage share of children for expats and tourists is nearly negligible.

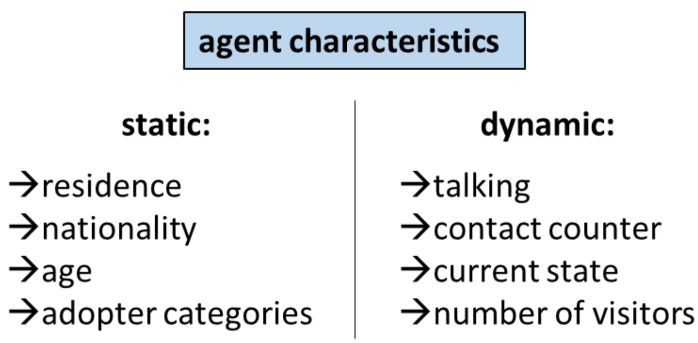

Figure 1. Static and Dynamic Agent characteristics

The last static characteristic is a description of the personal preferences of the agents concerning to the visit of new shopping malls, which are the projects under the real estate company. The nationalities of the agents are influenced the decision to visit the malls due to their different percentage shares of the visitor expectation groups. There are three expectation groups defined based on the innovation adopter categories: the Innovators, early adopters and late adopters (Rogers, 2003). They differ in the way they respond to the concept, number of shops, promotional activities and the social influence after the project already gained a certain popularity.

3.2 Spreading Process

The dynamic agent parameters as shown in Figure 1 are the determinants for the innovation spreading process. The process is spread over the boolean parameter "talking". Since the spreading should only depend on the network position and not on the Node ID a second parameter, describing the talking state in the last time step is used. Figure 2 displays the network diagram, where three nodes namely A, B, and C are seen. Each of the connection within a node or intra nodes represents the interaction or talking between the visitors. From Figure 2 it is seen that node B contains the more densely connections, representing the highest interactions or communications between the interested agents or visitors.

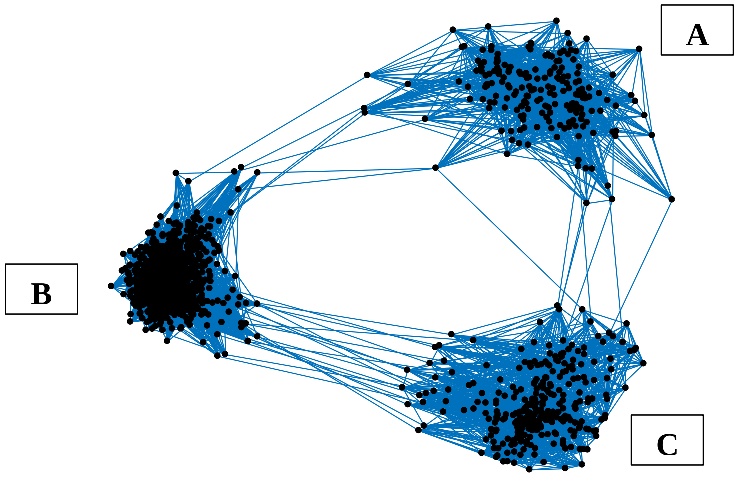

Figure 2. Representation of interactions between the visitors or agents in three different nodes

For each time step, each node who has at least three talking neighbors starts talking himself for two time steps. Each time an agent starts talking his contact counter is increased by one. As soon as the contact counter reaches a value higher than 20 a visiting decision is made. In case the agent chooses to visit the current state switches to positive for one time step, the number of visits is increased by one and the contact counter is reset to zero. If the agent decides not to go, he/she will proceed as before. For each node, the number of visits is recorded.

3.3 Decision Making Process

The adopter categories differ in their expectations concerning the characteristics of the case company. The total expectation of 1 splits up to the aspects concept, number of shops, promotional activities and social influence in the shopping malls. The values between 0 and 1 for all aspects and all adopter categories build up the visitor expectation matrix $\mathbf{M_{ex}}$.

The characteristics of the case company build up the characteristics vector $\mathbf{v_{ch}}$. As dynamic characteristics, the number of shops, the current state of promotion and the social influence were identified. In addition, there is the concept of the case company's project as a static parameter. For each time step, the adoption vector is evaluated by using the following Equation 1:

$$\mathbf{v_{adoption}} = \mathbf{M_{ex}} \mathbf{v_{ch}} \quad \text{......} \quad (1)$$

In case an agent is faced with the adoption decision, a random value between 0 and 1 is calculated. If the random value is smaller than the respective value of the adoption vector adoption takes place. To include the influence of the summer and winter season for the summer months the probability of a positive decision is decreased by decreasing the values of the characteristics vector $\mathbf{v_{ch}}$.

All of the static characteristics of the agents have an influence on his/her adoption decision in a certain way. The residence determines the position in the social network, the nationality determines how likely the agent is to belong to a certain adoption group and the age determines after how many contacts an adoption decision is made. The adopter category determines the expectation values and has therefore a direct influence on the likeliness of adoption. However, this ways of influencing the decision can be changed and adapted in multiple ways.

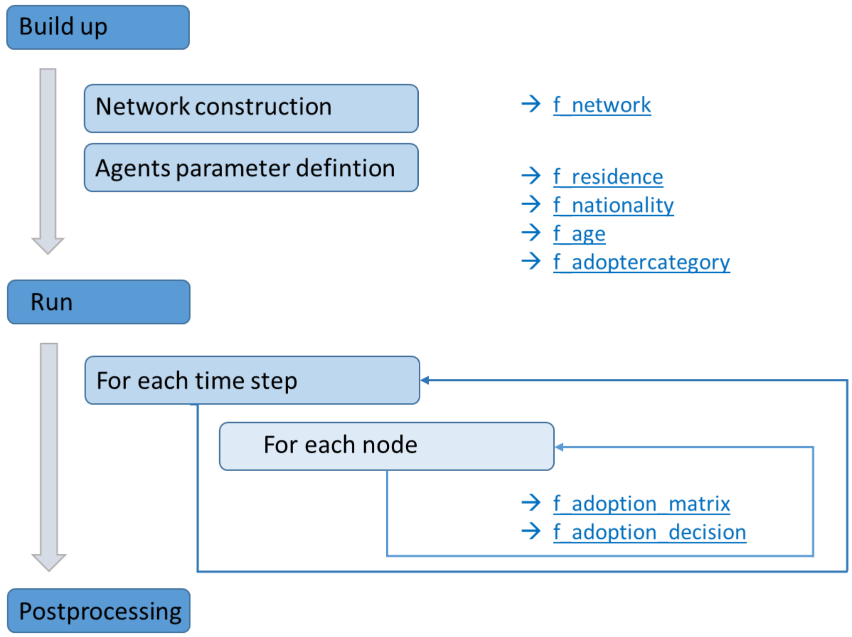

Figure 3. Flow chart for simulation algorithm

Figure 3 displays the flow chart of simulation algorithm. From Figure 3 it is seen that the first step of the algorithm is build up where construction of the network is done and parameters (e.g. residence, nationality, age, adopter category, etc.) of the agents are defined. After building the network for innovation diffusion process it is executed through running the network for each time step. For each time step, adaptation matrix and adoption decision are defined at each node. Final step of the algorithm is post processing where the collected data is analyzed to get the results.

4. Results Analysis

After collecting the necessary data from the network, it is processed by using the MATLAB - MathWorks software following the algorithm as highlighted in Figure 3. The outcomes from the analysis are presented accordingly. To have an insight in the working mechanism of the simulation the main output in terms of visitor numbers over time is plotted and presented in Figure 4. The results as highlighted over Figure 4 excludes the influence of the summer and winter season. The resulting graph in Figure 4 showed a relatively fast increase until a saturation value, around 350 visitors, where it oscillated irregularly. Overall, the behavior looks like expected. However, the time until saturation is rather short even though it was supposed to be the main topic of this research. The reaching of a saturation value at a certain point was expected but it is oscillating by a relatively big amplitude.

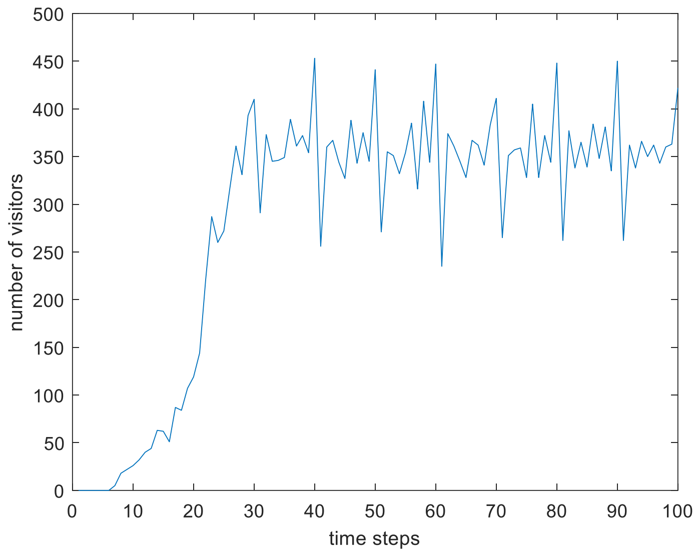

Figure 4. Test run results without season

The results are displayed in Figure 5 after including the effect of the summer and winter season. From Figure 5, it is noticed that the amplitudes increased and the saturation value decreased from 350 to around 250. This indicates the effect of seasons, when the number of visitors are varied quite substantially.

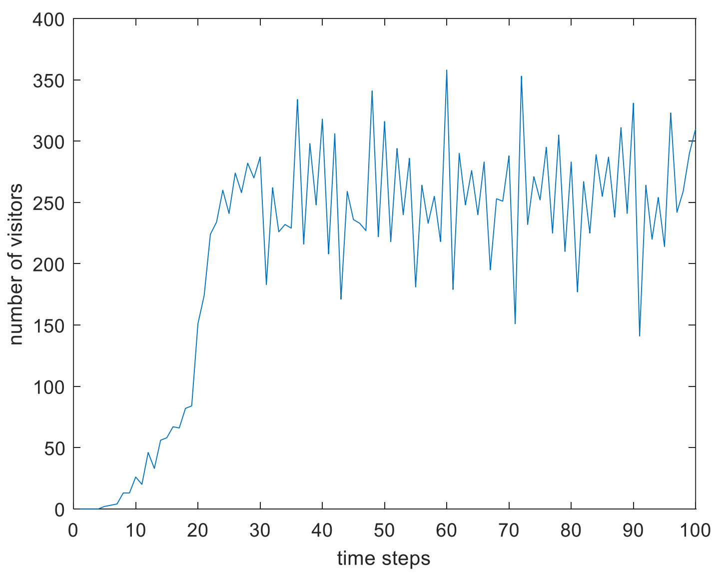

Figure 5. Test run including seasons

After the variation of some parameters such as nationalities, age group, etc., it is found that a decrease of the number of contacts until an adaption decision is made smoothed out the big oscillations. The oscillations become smoother after 600 visitors as displayed in Figure 6. It is also noticed that continuing the variations of more study parameters the saturation value increases further.

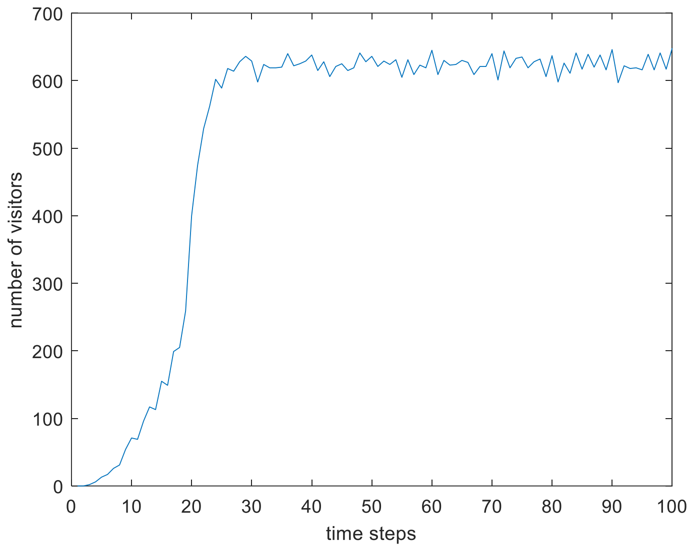

Figure 6. Test run smoothed after varying some study parameters

5. Discussions

A complex model including for the specific case important data was successfully implemented. The results are mainly as expected however; the graph indicates a few weaknesses of the model. Firstly, for a still relative small agent population of about 1000 agents and 100 time steps the execution time is over one hour. An increase of the population as planed to over a million agents is therefore not possible. Secondly, the rise until the saturation happens within only few time steps. This is however likely to be an effect of the for this consideration too small agent number. Additionally, the curve of visitors per time step shows an unsteady behavior which cannot be eliminated by simple parameter changes. This weakness in addition to the generally high number of parameters indicate how difficult it will be to adapt the model to the real application.

The model is based on a huge number of parameters. Whereas, some parameters can be detained from statistical data most of them are not that easily identifiable. Especially, the parameters describing individual decision making and personal preferences are not objectively quantifiable. This could partly be counteracted by creating customer surveys. Even though this would include a high effort, it would be not only helpful for this model but for general strategic decisions concerning the case project.

Therefore, a rather big part of the data has to be estimated, while at the same time the full model is very sensitive to a change of parameter values. The same is valid for the design of the networks structure. This is a big downside of the modelling process, which induces both an uncertainty of the validity of the model and a high specification on the current application.
Finally, there are many other features which could be included depending on how detailed the model should be. For instance, the chance of visitor number during the seasons or more detailed personal characteristics of the agents such as income level.

6. Conclusions

This paper describes a possible structure of an agent-based innovation diffusion model, where simulating a process of visitor development employing an agent-based approach. Interconnected small-world networks are used to describe the social structure. Furthermore, a complex decision making processes considering the static and dynamic characteristics of each agent is included. The results from estimated values is promising. However, due to time-related difficulties in data acquiring the model is not yet adapted to the real world values. This paper covers only the building-up of an agent-based model for a development in the past. This model was not yet employed for forecasts or marketing mix analysis. These are possible topics for further research. Overall, despite some downsides the potential for future research is apparent.

Acknowledgements

The authors would like to acknowledge the contribution of Miss Franziska Krebs, of Karlsruhe Institute of Technology, Germany, for her active participation towards project discussions and the MATLAB - MathWorks coding. This was part of her training requirement of The International Association for the Exchange of Students for Technical Experience (IAESTE) program.

References

Auchincloss, A.H., and Roux, A.V.D., A new tool for epidemiology: the usefulness of dynamic-agent models in understanding place effects on health, *American Journal of Epidemiology*, vol. 168, no. 1, pp. 1–8, 2008.

Barker, K., Diffusion of innovations: A world tour, *Journal of Communication*, vol. 9, pp. 131–137, 2004.

Bass, F.M., A new product growth for model consumer durables, *Management Science*, vol. 15, no. 5, pp. 215–227, 1969.

Bonabeau, E., Agent-based modeling: methods and techniques for simulating human systems, *Proceedings of the National Academy of Sciences*, vol. 99(90003), pp. 7280–7287, 2002.

Borshchev, A. and Fillipov, A., From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools, *Proceedings of the 22nd International Conference of the Systems Dynamics Society*, pp. 1–22, Oxford, 2004.

Bousquet, F., and Page, C.L., Multi-agent simulations and ecosystem management: a review, *Ecological Modelling*, vol. 176, no. 3-4, pp. 313–332, 2004.

Choi, H., Kim, S-H., and Lee, J., Role of Network Structure and Network Effects in Diffusion of Innovations, *Industrial Marketing Management*, vol. 39, no. 1, pp. 170–177, 2010.

Eliashberg, J., Chatterjee, R., Mahajan, V., and Wind, Y., Stochastic issues in innovation diffusion models, *In Innovation Diffusion Models of New Product Acceptance*, pp. 151–199, Ballinger Publishing, Cambridge, MA, 1986.

Greenhalgh, T., Robert, G., Macfarlane, F., Bate, P., Kyriakidou, O., and Peacock, R., Storylines of Research in Diffusion of Innovation: A Meta-narrative Approach to Systematic Review, *Social Science & Medicine,* vol. 61, pp. 417–430, 2005.

Infante, D., *Catching-up, Innovation and Diffusion Processes*, Denmark, Roskilde Universitetscenter, 1995.

Kiesling, E., Gunther, M., Stummer, C., and Wakolbinger, L.M., Agent-based simulation of innovation diffusion: a review, *Central European Journal of Operations Research*, vol. 20, no. 2, pp. 183–230, 2012.

Kiesling, M.G., Planning the market introduction of new products: An agent-based simulation of innovation diffusion, *Doctoral Dissertation*, University of Vienna, Austria, 2011.

Kiesling, E., Gunther, M., Stummer, C., and Wakolbinger, L.M., Agent-based simulation of innovation diffusion: a review, *Central European Journal of Operations Research*, vol. 20, no. 2, pp. 183-230, 2002.

Manrai, A.K., Mathematical models of brand choice behaviour, *European Journal of Operational Research*, vol. 82, no. 1, pp. 1–17, 1995.

Mahajan, V., Muller, E., and Bass, F. M. New product diffusion models in marketing: a review and directions for further research, *Journal of Marketing*, vol. 54, no. 1, pp. 1–26, 1990.

Mahajan, V. and Muller, E., Innovation diffusion and new product growth models in marketing, *The Journal of Marketing*, vol. 43, no. 4, pp. 55–68, 1979.

Malleson, N., Agent-Based Modelling of Burglary, *PhD Thesis*, University of Leeds, 2010.

Rogers, E.M., *Diffusion of Innovations*, Fifth Edition, Free Press, New York, p. 221, 2003.

Rogers, E., and Shoemaker, F., *Communication of Innovations: A Cross-cultural Approach*, Free Press, 1971.

Turner, A. and Penn, A., Encoding natural movement as an agent-based system: an investigation into human pedestrian behaviour in the built environment, *Environment and Planning B: Planning and Design*, vol. 29, no. 4, pp. 473–490, 2002.

Valente, T.W., and Davis, R.L., Accelerating the diffusion of innovations using opinion leaders, *The Annuals of the American Academy of Political and Social Science*, vol. 566, pp. 55–67, 1999.

Wejnert, B., Integrating models of diffusion of innovations: A conceptual framework, *Annual Review of Sociology*, vol. 28, pp. 297–326, 2002.

Weiss, G., *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence*, MIT Press, Cambridge, MA, 1999.

Wilkinson, S., Focus group research, *Qualitative research: Theory, Method and Practice*, pp. 177–199, 2004.

Biographies

Emad Summad has a PhD in Industrial Engineering. He is specializing on policy issues for entrepreneurship and innovation in the knowledge-based economy. Dr. Summad currently teaches Innovation and Entrepreneurship at College of Engineering, Sultan Qaboos University. His research interest is on new perspectives on adoption and diffusion of innovations; using agent-based modelling to understand what happens when innovations are adopted by individual consumers and diffused in aggregate markets. What makes one innovation a screaming success while another just fade away! His work also includes governing innovation using social network structure and dynamics analysis. He promotes for technology-based lean startups.

Mahmood Al-Kindi is working as an Assistant Professor at Department of Mechanical and Industrial Engineering, Sultan Qaboos University, Muscat, Sultanate of Oman. He received his PhD from Illinois at Urbana Champaign, USA in 2010. He received his Master of Science degree from the Louisiana State University, USA in 2003. His research interests lies in the area of Quality and Six Sigma, Innovation and Business Entrepreneurship, Lean Manufacturing, Production Planning and Control. He has published several research papers in both international journals and conference proceedings.

Ahm Shamsuzzoha has been working as an Assistant Professor, Department of Mechanical and Industrial Engineering, Sultan Qaboos University, Muscat, Sultanate of Oman. He received his PhD in Industrial Management (Department of Production) from the University of Vaasa, Finland and his Master of Science (Department of Mechanical Engineering) degree from the University of Strathclyde, Glasgow, UK. His major research and teaching interest lies in the area of enterprise collaborative networks, operations management, product customization, simulation modelling and supply chain management. He has published several research papers in both reputed international journals and conferences.